

Symbols and Abbreviations

\vec{A}	magnetic vector potential
A	line current density; cross-section area
a	number of parallel current paths of the stator (armature) winding
\vec{B}	vector magnetic flux density
B	magnetic flux density; damping of the system
b	instantaneous value of the magnetic flux density; width of slot
b_p	pole shoe width
C_f	cost of frame
C_{ins}	cost of insulation
C_0	cost of all other components independent of the shape of the machine
C_{PM}	cost of PMs
C_{rc}	cost of the rotor core
C_{sh}	cost of shaft
C_w	cost of winding
c_{Cu}	cost of copper conductor per kg
c_E	armature constant (EMF constant)
c_{Fe}	cost of ferromagnetic core per kg
c_{ins}	cost of insulation per kg
c_p	specific heat at constant pressure
c_{PM}	cost of PMs per kg
c_{steel}	cost of steel per kg
c_v	heat capacity

D	diameter; duty cycle of power semiconductor switches
D_{in}	inner diameter of PMs equal to the inner diameter of stator bars
D_{out}	outer diameter of PMs equal to the outer diameter of stator bars
E	EMF (<i>rms</i> value); electric field intensity
E_f	EMF per phase induced by the rotor without armature reaction
E_i	internal EMF per phase
e	instantaneous EMF; eccentricity
F	force
F_{12}	shape factor of two surfaces involved in radiation
\mathcal{F}	space and/or time distribution of the MMF
\mathcal{F}_a	armature reaction MMF
\mathcal{F}_{exc}	MMF of the rotor excitation system
f	frequency; friction factor
G	permeance; gap ratio g/R
g	air gap (mechanical clearance); gravitational acceleration
Gr	Grashof number
g'	equivalent air gap
\vec{H}	vector magnetic field intensity
H	magnetic field intensity
h	height; heat transfer coefficient
h_M	height of the PM
I	electric current
I_a	stator (armature) current
i	instantaneous value of current; enthalpy
\vec{J}	vector electric current density
J	moment of inertia
J_a	current density in the stator (armature) winding
K_c	current regulator gain
K_i	inverter gain
k	coefficient, general symbol; thermal conductivity
k_{1R}	skin effect coefficient for the stator conductor resistance
k_{ad}	reaction factor in d -axis
k_{aq}	reaction factor in q -axis

k_C	Carter's coefficient
k_d	inner-to-outer diameter ratio $k_d = D_{in}/D_{out}$
k_{d1}	distribution factor for fundamental
k_E	EMF constant $k_E = c_E \Phi_f$
k_f	form factor of the field excitation $k_f = B_{mg1}/B_{mg}$
k_i	stacking factor of laminations
k_{ocf}	overload capacity factor $k_{ocf} = T_{max}/T_{shr}$
k_{p1}	pitch factor for fundamental
k_{sat}	saturation factor of the magnetic circuit due to the main (linkage) magnetic flux
k_T	torque constant $k_T = c_T \Phi_f$
k_{w1}	winding factor $k_{w1} = k_{d1} k_{p1}$ for fundamental
L	inductance; length
l_{1e}	length of the one-sided end connection
L_i	armature stack effective length
l_M	axial length of PM
M	mutual inductance
M_o	momentum
m	number of phases; mass
\dot{m}	mass flow rate
m_a	amplitude modulation ratio
m_f	frequency modulation ratio
N	number of turns per phase; number of machines
Nu	Nusselt number
n	rotational speed in rpm; independent variables
n_0	no-load speed
P	active power
P_{elm}	electromagnetic power
P_{in}	input power
P_{out}	output power
Pr	Prandtl number
ΔP	active power losses
ΔP_{1Fe}	stator core losses

ΔP_{1w}	stator winding losses
ΔP_{2Fe}	rotor core losses
ΔP_e	eddy current losses in stator conductors
ΔP_{fr}	friction losses
ΔP_{PM}	losses in PMs
ΔP_{rot}	rotational (mechanical) losses
ΔP_{wind}	windage losses
Δp	specific core loss
p	number of pole pairs; pressure
p_r	radial force per unit area
\wp	wetted perimeter
Q	electric charge; reactive power; volumetric flow rate
Q_{en}	enclosed electric charge
R	radius; resistance
R_1	armature winding resistance of a.c. motors
R_{in}	inner radius of PMs equal to the inner radius of stator bars
R_{out}	outer radius of PMs equal to the outer radius of stator bars
Re	Reynolds number
$\mathfrak{R}_{\mu g}$	air gap reluctance
$\mathfrak{R}_{\mu la}$	external armature leakage reluctance
$\mathfrak{R}_{\mu M}$	permanent magnet reluctance
S	apparent power; surface
S_M	cross section area of PM; $S_M = w_M L_M$ or $S_M = b_p L_M$
s	cross section area of stator conductor
s_1	number of stator slots equal to the number of stator teeth
T	torque
T_d	electromagnetic torque developed by the machine
T_{drel}	reluctance torque
T_{dsyn}	synchronous or synchronizing torque
T_m	mechanical time constant
T_{sh}	shaft torque (output or load torque)
t	time; slot pitch
U	internal energy

u	tangential velocity
V	electric voltage; volume
v	instantaneous value of electric voltage; linear velocity
W	energy produced in outer space of PM; rate of change of the air gap energy
W_m	stored magnetic energy
w	energy per volume, J/m^3 ; radial velocity
w_M	width of PM
X	reactance
X_1	stator winding leakage reactance
X_{ad}	d -axis armature reaction (mutual) reactance
X_{aq}	q -axis armature reaction (mutual) reactance
X_{sd}	d -axis synchronous reactance; $X_{sd} = X_1 + X_{ad}$
X_{sq}	q -axis synchronous reactance; $X_{sq} = X_1 + X_{aq}$
\mathbf{Z}	impedance $\mathbf{Z} = R + jX$; $ \mathbf{Z} = Z = \sqrt{R^2 + X^2}$
α	complex attenuation constant of electromagnetic field
α_i	effective pole arc coefficient $\alpha_i = b_p/\tau$
γ	form factor of demagnetization curve of PM material
δ	power (load) angle
δ_i	inner torque angle
ϵ	eccentricity
ε	emissivity; surface spectral property
η	efficiency
γ	equivalent sand grain roughness
θ	rotor angular position for brushless motors
ϑ	temperature; angle between \mathbf{I}_a and \mathbf{I}_{ad}
λ	coefficient of leakage permeance (specific leakage permeance)
λ_T	turbulent parameter
μ	dynamic viscosity
μ_o	magnetic permeability of free space $\mu_o = 0.4\pi \times 10^{-6} \text{ H/m}$
μ_r	relative magnetic permeability
μ_{rec}	recoil magnetic permeability
μ_{rrec}	relative recoil permeability $\mu_{rrec} = \mu_{rec}/\mu_o$

ν	number of the stator ν th harmonic; kinematic viscosity
ξ	reduced height of the stator conductor
ρ	specific mass density
σ	electric conductivity; Stefan-Boltzmann constant
σ_f	form factor to include the saturation effect
σ_p	output coefficient
σ_r	radiation factor
τ	average pole pitch; thermal time constant
Φ	magnetic flux
Φ_f	excitation magnetic flux
Φ_l	leakage flux
ϕ	power factor angle
Ψ	flux linkage $\Psi = N\Phi$; angle between \mathbf{I}_a and \mathbf{E}_f
ψ	flux linkage
Ω	angular speed $\Omega = 2\pi n$
ω	angular frequency $\omega = 2\pi f$

Subscripts

a	armature (stator)
avg	average
c	conduction
cv	control volume
Cu	copper
d	direct axis; differential; developed
e	end connection; eddy-current
elm	electromagnetic
eq	equivalent
exc	excitation
ext	external
Fe	ferromagnetic
f	field; forced
fr	friction; free

<i>g</i>	air gap
<i>h</i>	hydraulic; hysteresis
<i>in</i>	inner
<i>l</i>	leakage
<i>M</i>	magnet
<i>m</i>	peak value (amplitude)
<i>n, t</i>	normal and tangential components
<i>out</i>	output, outer
<i>q</i>	quadrature axis
<i>r</i>	rated; remanent; radiation; rotor
<i>r, θ, z</i>	cylindrical coordinate system
<i>rel</i>	reluctance
<i>rot</i>	rotational
<i>s</i>	slot; synchronous; system; stator
<i>sat</i>	saturation
<i>sh</i>	shaft
<i>st</i>	starting
<i>syn</i>	synchronous or synchronizing
<i>t</i>	teeth; total
<i>u</i>	useful
<i>v</i>	convection
<i>vent</i>	ventilation
<i>wind</i>	windage
<i>y</i>	yoke
<i>x, y, z</i>	cartesian coordinate system
1	stator; fundamental harmonic; inlet
2	rotor; exit

Superscripts

inc	incremental
(sq)	square wave
(tr)	trapezoidal

Abbreviations

A/D	analog to digital
AFPM	axial flux permanent magnet
AIFI	American Iron and Steel Industry
a.c.	alternating current
BPF	band pass filtering
CAD	computer-aided design
CPU	central processor unit
DSP	digital signal processor
d.c.	direct current
EDM	electro-discharge machining
EMALS	electro-magnetic aircraft launch system
EMF	electromotive force
EMI	electromagnetic interference
EV	electric vehicle
FDB	fluid dynamic bearing
FEM	finite element method
FPGA	field programmable gate array
HDD	hard disk drive
HEV	hybrid electric vehicle
IC	integrated circuit
IGBT	insulated-gate bipolar transistor
ISG	integrated starter-generator
LPF	low pass filter
MMF	magnetomotive force
MMT	moving magnet technologies
MOSFET	metal oxide semiconductor (MOS) field effect transistor
MVD	magnetic voltage drop
NdFeB	neodymium iron boron
PFM	pulse frequency modulation
PLD	programmable logic device
PM	permanent magnet

PWM	pulse width modulation
RFI	radio frequency interference
RFPM	radial flux permanent magnet
SEMA	segmented electro-magnetic array
SMC	soft magnetic composite
SmCo	samarium cobalt
SSC	solid state converter

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